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Job No. 11126

STUDIES OF MANUAL CONTROL SYSTEMS

Progress Report No. 7

for the period 19 January 1965 to 18 April 1965

10 May 1965

Submitted to:

National Aeronautics and Space Administration
600 Independence Avenue
Washington, D. C. 20546

Attention: Dr. T. L. K. Smull

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I. INTRODUCTION

This is a brief summary of the work we have done under contract NASw-668 during the three-month period beginning 19 January 1965 and ending 18 April 1965, the fourth quarter of the second year of the contract. This report contains a preliminary analysis of the experimental data that has been recently obtained. A complete analysis of experimental results will be presented in the forthcoming annual report.

We have spent the past quarter repeating the experiments described in previous progress reports with more subjects and with better experimental control. The difference between single- and two-axis performance was investigated under three classes of experimental conditions: (1) symmetric conditions; with the bandwidth of the input forcing function and the controlled dynamics the same on each axis, (2) mixed bandwidths, where the input bandwidths were dissimilar but the controlled dynamics were identical, and (3) mixed dynamics, where the input bandwidths were identical but the controlled dynamics were dissimilar.

For each experimental condition the hypothesis tested was that tracking performance in a given axis would not differ in the following two situations: (1) when that axis alone was tracked, and (2) when the two axes were tracked simultaneously. Performance was quantified in terms of normalized mean squared errors and in terms of describing functions.

II. EXPERIMENTAL DESIGN

The apparatus and experimental procedures have been fully described in Reports 5 and 6. This section describes the changes in procedure that were made for this particular set of experiments.

A. FORCING-FUNCTION BANDWIDTH

The input signals were pseudo-Gaussian with augmented rectangular spectra. The bandwidth of the secondary component was 9 rad/sec in all cases, whereas the bandwidth of the primary component was one of the experimental variables.

1. Symmetric Conditions: The bandwidths of the primary components were the same on the two axes and were either 1.5, 2.5, or 4.0 rad/sec.

2. Mixed Bandwidths: The bandwidth on the Y (vertical) axis was 4.0 and that on the X (horizontal) axis was 1.5 rad/sec.

3. Mixed Dynamics: The bandwidths were 4.0 rad/sec. on both axes.

B. MEAN-SQUARED INPUT

For most experiments the amplitudes of the input signals were adjusted so that the mean-squared deviation on each

axis would be 4.0 cm^2. Thus, the forcing function had a mean-squared deviation of 4 cm^2 for single-axis tracking and 8 cm^2 for two-axis tracking. Even though the MS inputs were the same on each axis, the MS tracking errors were often noticeably different because of the nature of the experimental conditions or peculiarities of the subjects. Some experiments were redesigned so that the MS errors would be roughly the same on the two axes. This was achieved through readjustment of the MS input signals, but always in such a way that the total MS input in the two-axis situation would be 8 cm^2.

C. CONTROLLED-DYNAMICS GAIN

1. Symmetric Conditions: The controlled dynamics had the form K/s^2, where K was the same for each axis and was adjusted to provide roughly the same control effectiveness under the three experimental conditions. Relative values of K were 16 for a BW of 4.0 rad/sec, 8 for a BW of 2.5, and 4 for a BW of 1.5.

2. Mixed Bandwidths: Even though the input bandwidths differed, the gains were identical (relative value of 16) so that maximum control-display comparability would be maintained.

3. Mixed Dynamics: The controlled dynamics were unity on the X axis and 16/s2 on Y. These values were chosen to provide roughly the same control effectiveness on the two axes.

D. CIRCLE GAIN

1. Symmetric Conditions: The circle gains were the same on each axis and were adjusted on the basis of the single-axis errors to provide a circle diameter of about 0.6 cm on the average. The circle gains were halved for the two-axis situation so that the subject would see similar-sized circles for the two-axis and single-axis conditions.

2. Asymmetric Conditions: Since the errors were different on the two axes, the circle gains on the two axes were also unequal and were adjusted so that the average circle diameter would be 0.6 cm when either axis was tracked alone. The circle gains (computed on the basis of single-axis performance) were halved when the subject tracked two axes.

III. RESULTS

A. SYMMETRIC CONDITIONS

Differences between single- and two-axis performance on a normalized mean squared basis are summarized in Table I and II. Table I is subdivided into three sections, each of which pertains to a particular forcing-function bandwidth. Each entry represents an average percent difference, defined as the average difference between two- and one-axis performance divided by the average single-axis performance times 100. A negative entry indicates that two-axis performance was superior to single-axis performance. Averages were computed on each axis for the three subjects considered individually and for the subjects considered together. The statistical significance was computed on the assumption of a t distribution of the entries; those entries having a confidence level of less than 0.05 are so indicated. The confidence level indicates the probability that an error will be made if the null hypothesis is rejected.

There were differences in behavior among the subjects, and for each subject there were generally differences between X and Y-axis results. Subject RL showed the least difference between single- and two-axis performance and also the least difference between X- and Y-axis behavior.* The greatest

*In this context, "behavior" refers to the percent difference between two- and single-axis performance. Identical behavior on the two axes implies identical percent differences. It does not imply, however, that the performance was the same for the two axes.

percent difference for him was 13%, which occurred on the Y axis for bandwidths of 4 and 1.5 rad/sec. None of the differences for this subject were significant at the 0.05 level. (In general, the sensitivity of the experiments was such that a difference of from 10 to 15% would be significant at the 0.05 level.) Subject BL showed the greatest differences, the largest being 43% for the Y-axis with an input bandwidth of 1.5. Although none of the X-axis differences were significant, the Y-axis differences were all significant below the 0.01 level and ranged from 31 to 43%. Subject CP showed differences of 20 to 34% on the Y axis, all of which were significant below the 0.05 level. On the other hand, all his X-axis entries are negative, indicating superior performance for that axis in the two-axis situation. One of these entries (-12%, bandwidth of 1.5 rad/sec) is significant at the 0.05 level.

We were surprised to observe that the differences between one- and two-axis performance for a given subject did not depend in any consistent way on the difficulty of the task (which is directly related to input bandwidth). Changes in behavior with bandwidth for a given subject were less than the differences between subjects under similar experimental conditions. Thus, it makes more sense to average across conditions than across subjects. Table II shows that the sensitivity of the computational procedures was enhanced by averaging over the three bandwidth conditions for each subject. The data were suitably normalized to account for the differences in performance levels under the three conditions. All but one of the resulting entries were significant to the 0.05 level. The results are consistent with those of Table I, with the percent differences ranging from -9.5 to 36%.

Preliminary analysis of Bode plots (not shown in this report) indicates that the primary difference between single- and two-axis results is a relatively uniform difference in the gain curves of a few db. Figure 1 shows a comparison of the open-loop describing functions obtained for a single subject for each of the three forcing functions. The describing functions corresponding to input bandwidths of 2.5 and 4 rad/sec are substantially the same, with gain crossover around 6 rad/sec and phase margins from 10-20°. The curves for the 1.5 rad/sec input bandwidth have gain crossover at 4 rad/sec.

B. MIXED BANDWIDTHS

Data have been obtained from two subjects. For the first experiment, the rms levels of the input signals were the same on the two axes, whereas the bandwidths were 1.5 and 4.0 rad/sec on the X and Y axes respectively. Thus, the Y-axis task was more difficult, and the tracking errors on that axis were greater. The results of this experiment are summarized in the first two rows of Table III. Notice that the Y-axis errors were from 4 to 6 times as great as those on the X axis. The two subjects behaved differently under these conditions. Subject CP showed no significant differences in performance on either axis between the one- and two-axis conditions. On the other hand, RL's performance deteriorated by almost 100% on the X-axis and improved by 16% on the Y axis, both numbers being significant at the 0.01 level.

We hypothesized that in the two-axis situation, subject RL has been devoting the greater share of his effort to reducing the Y-axis errors, to the detriment of X-axis performance, because the Y-axis errors were bigger. To test this hypothesis, the rms levels of the forcing functions were readjusted so that the absolute tracking errors would be roughly the same on each axis. This procedure was not expected to change the relative performance (normalized mean squared error) on either axis.

The result of this modification is shown in the third row of Table III. Although the X- and Y-axis relative performances continued to differ by a factor of about 6, the differences between single- and two-axis performances on each axis were reduced to insignificance.

C. MIXED DYNAMICS

Experiments are in progress; the results will be presented in the annual report.

IV. DISCUSSION

A discussion of results will appear in the forthcoming annual report, by which time the full body of data will have been acquired and analyzed.

Table I

Summary of Data for Symmetric Conditions

Subject	Percent Difference	
	X Axis	Y Axis
	wi=4	
RL	8.5	13
CP	-9.0	20*
BL	12	35**
3 subj.	3.5	22**
	wi=2.5	
RL	0.9	2.5
CP	-7.5	34***
BL	10	31***
3 subj.	-4.1	22***
	wi=1.5	
RL	-0.2	13
CP	-12*	34**
BL	8.1	43**
3 subj.	-0.8	30.4***

Confidence Levels

*	0.05
**	0.01
***	0.001

Table II

Summary of Data for Symmetric Conditions
Percent Differences Averaged over Three BW Conditions

Subject	Percent Difference	
	X Axis	Y Axis
RL	3.1	9.5*
CP	-9.5**	30***
BL	10.2**	36***

Confidence Levels

*	0.05
**	0.01
***	0.001

Table III

Results of Mixed Bandwidth Experiments

Subject	Axis	MS Input cm^2	1-Axis Perf.	Percent Diff.
CP	X	4.0	.031	9.3
	Y	4.0	.13	-2.0
RL	X	4.0	.017	96***
	Y	4.0	.12	-16**
RL	X	6.9	.022	-4.5
	Y	1.1	.15	-6.4

Confidence Levels

** .01

*** .001

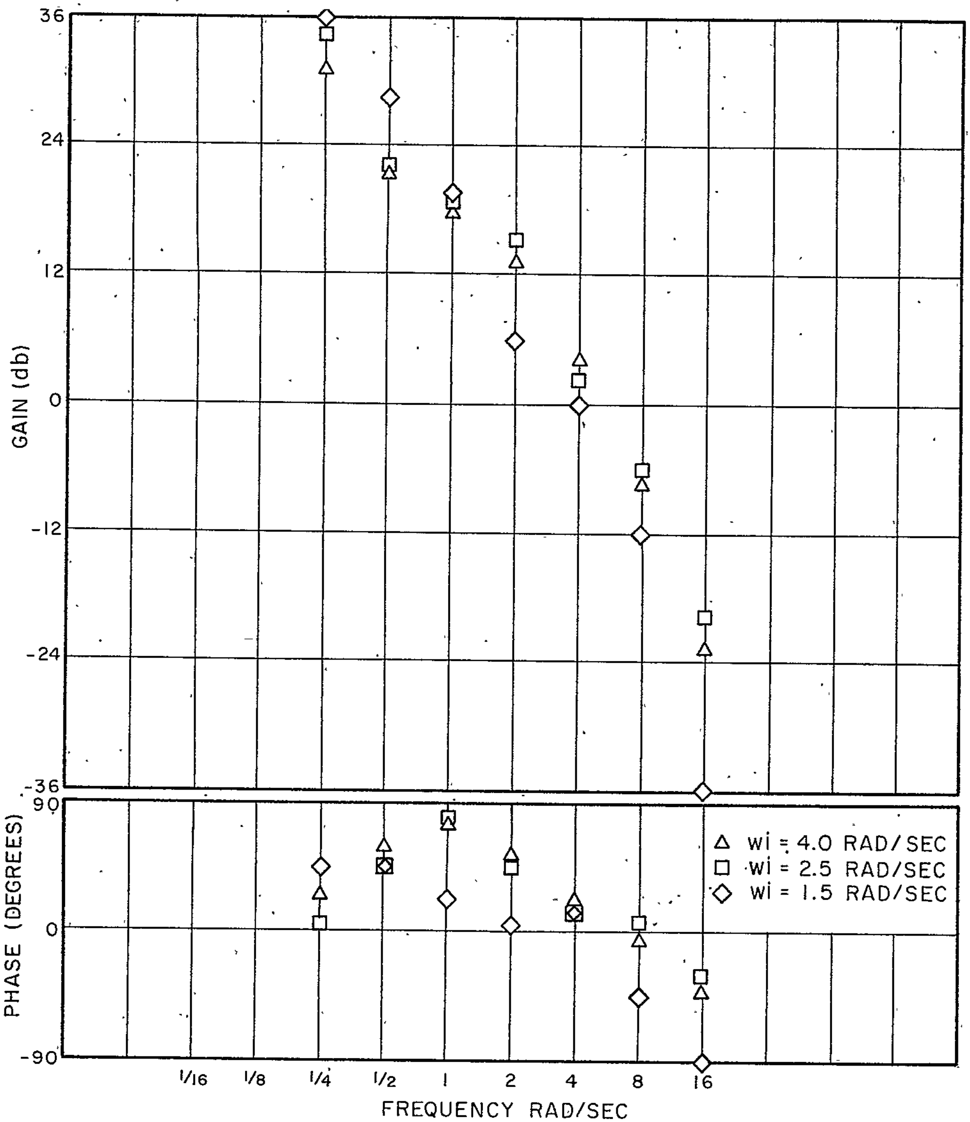

FIG. 1 OPEN-LOOP DESCRIBING FUNCTIONS, Y AXIS ACCELERATION DYNAMICS